GBM Burst Trigger, Classification, and Location

1. Background - BATSE burst trigger

The GBM will use a trigger algorithm similar to, but more capable than, the trigger used on BATSE. The data used for triggering BATSE had a time resolution of 64 ms and comprised 4 energy channels: 25-50 keV, 50-100 keV, 100-300 keV, and >300 keV. Although any combination of energy channels could be used for the trigger, the baseline was channels 2+3, corresponding to 50-300 keV. The time scales used were 64 ms, 256 ms, and 1024 ms. The 1024 ms time scale was the most sensitive; 93% of all BATSE bursts were bright enough to trigger this on this time scale. A trigger was declared whenever the count rate in at least two detectors exceeded a threshold significance level above background. This threshold was usually set at 5.5 sigma on each of the three trigger timescales. The backgrounds in each detector were measured at intervals of ~17 seconds.

2. GBM Trigger Algorithm

The GBM will trigger using data available on 16 ms intervals in 8 energy channels. Baseline trigger time scales will be 16ms, 64 ms, 256 ms, 1.024 s, 4.096 s, and 16.384 s. Three independent energy ranges will be selected, one of which will always be 50-300 keV. As with BATSE, a trigger requires two detectors above threshold. We expect to be able to set the thresholds on GBM at 4.5 sigma above background. On BATSE, setting the thresholds this low would have resulted in many more triggers from non-burst sources, such as Cygnus X-1. The smaller GBM detectors will not have this problem. The backgrounds will be predicted by fitting a quadratic to the time history of the rates of each detector. Parameters of the algorithm (time scales, energy ranges, background time scale) can be modified by command. The algorithm can be revised by software upload.

GBM has a level II requirement for the on-board trigger threshold of <1.0 photons/cm2-s and a goal of <0.75 photons/cm2-s. The threshold is defined as an efficiency of 50% over the visible sky, and the flux refers to the 50 keV to 300 keV energy range, with a 1 second burst duration. A simulation of the GBM performance (described in the Appendix) established that the trigger threshold as defined here is 0.71 photons/cm2-s.

Since the trigger algorithm is so similar to BATSE, it is straightforward to compute the expected GBM burst trigger rate. Our simulation indicates that we will trigger on about 200 bursts per year, assuming a significance threshold of 4.5 sigma and 16% dead time from SSA passages. This calculation accounts only for BATSE-like triggers – 50 keV to 300 keV on timescales of 64 ms, 256 ms, and 1024 ms.

3. On-Board Classification Algorithm

Triggers of BATSE arose from several sources: GRBs, solar flares, SGRs, hard X-ray transients, Cygnus X-1, particle precipitation events, and TGFs (Terrestrial Gamma Flashes). We anticipate that GBM will trigger on about 200 bursts per year, and very roughly another 200 triggers per year due to other types of events. TGF's and Cygnus X-1 fluctuations will seldom, if ever, trigger GBM since these events were usually close to BATSE's threshold. Particle precipitation events that occur at the location of the instrument are easily identified because they tend to illuminate all detectors approximately equally. GBM will use a Bayesian analysis of event characteristics to classify each trigger for which a good location can be obtained. The relevent data from each event are celestial coordinates (effective for distinguishing known astronomical sources), hardness ratio (effective for solar flares and SGRs), and McIlwain L coordinate (effective for distinguishing particle precipitation events). Probability distributions and Bayesian priors can be estimated from BATSE data but will be refined with on-orbit experience.

We simulated the performance of GBM using BATSE data. This has the obvious weakness that the priors and the location error distributions will be different for the smaller GBM detectors. Nevertheless, the results were encouraging. If an event is classified as a burst only when its Bayesian probability of being a burst is >70%, then GBM would misclassify bursts about 10 times per year, and misclassify other events as bursts about 20 times per year. The latter number is highly uncertain as it depends on the probability of new X-ray transients occurring, and how many triggers it generates before its location can be determined and included in the algorithm. Triggers from a previously unknown X-ray transient will be initially classified as bursts, unless they are have distinctly softer spectra.

An event intense enough to generate a repoint request should have smaller than average location error, higher than average probability of correct classification, and higher than average probability of being a burst in the first place.

4. On-board location algorithm

We investigated several different approaches for calculating locations on-board. The approach chosen was to load a table of relative count rates in each NaI detector covering a grid of sky locations with ~5 degree separation. The table size is 1634 sky points * 12 detectors * 2 bytes = 39 kbyte, not significantly impacting our memory budget. The tables will include the effects of spacecraft and atmospheric scattering – relegating these time-consuming calculations to ground software. The on-board software simply normalizes the detectors rates (above background) and exhaustively searches the grid for the best match. The atmospheric scattering is computed assuming GLAST is zenith pointing and assumes a specific typical burst spectrum.

The primary contributors to the systematic error in location are: 1) variations in atmospheric scattering due to off-zenith pointing, 2) discreteness of the grid points on the sky, and 3) variations in burst spectra. These effects, plus statistical errors, were investigated by simulation using bursts with fluence of 10 photons/cm2 and a distribution of spectral parameters as observed by BATSE. Table 1 gives the 1 sigma (68%) and 2 sigma (95%) errors as a function of GLAST zenith angle. GBM easily meets the level 2 goal of on-board location error <15 degrees.

Zenith angle (deg.)	1 sigma error (deg.)	2 sigma error (deg.)
0	3	6
15	3	7
30	4	10
45	6	14
60	7	21
75	9	29
90	13	40

5. Effective Area and Field of View

GBM has a requirement for effective FOV of 8 steradians and a goal of 10 steradians. Effective FOV is defined as the effective area integrated over the sphere devided by the peak effective area. Our simulation calculates the GBM effective area for the NaI detectors as 9.5 steradians. Effective FOV was not computed for the BGO detectors, which are effectively omnidirectional and view the entire sphere.

Figures 1 and 2 show the effective area of the NaI detectors over the sky in units of detector area (126 cm2). In Figure 1, penetration of gamma rays through the back and sides of the detectors is included. In Figure 2, only projected area in the forward direction is included.

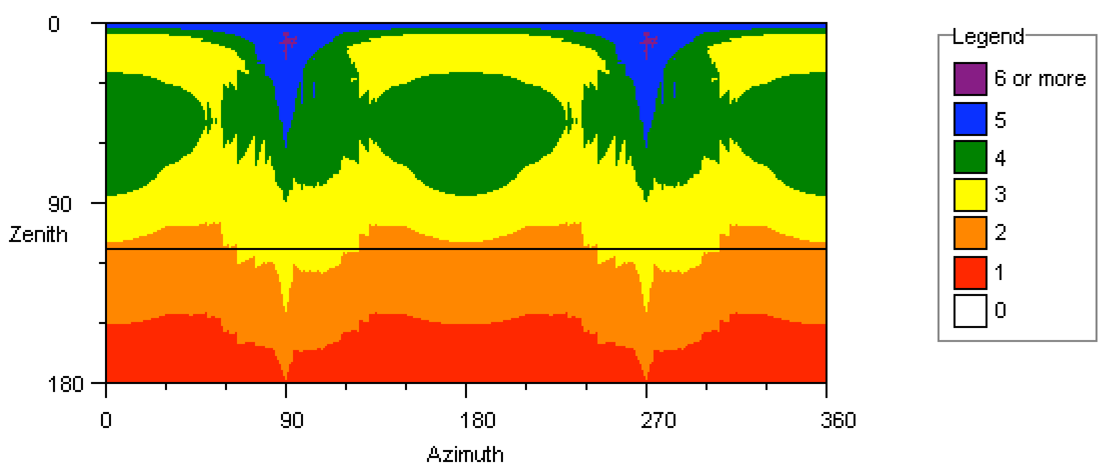

Figure 1: Total projected area versus direction in units of detectors (truncated). The horizontal black line represents the Earth horizon.

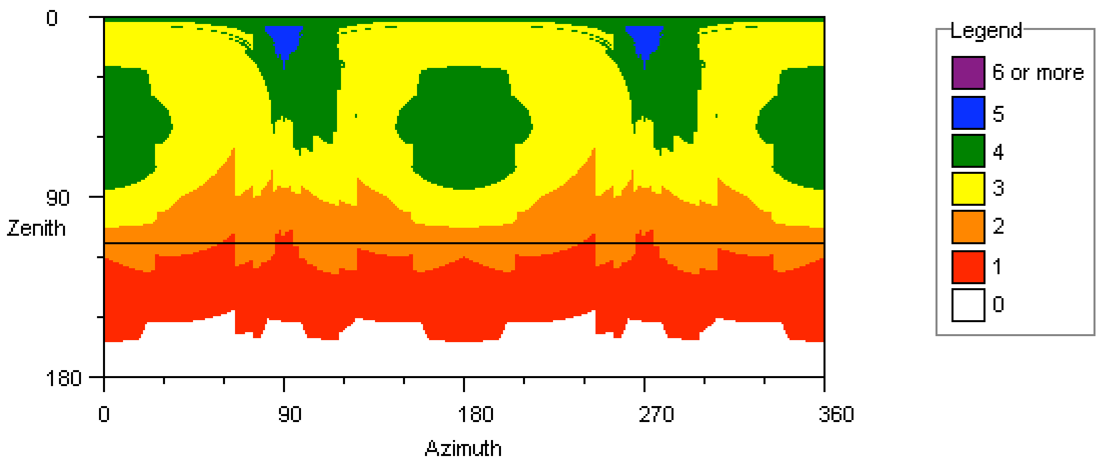

Figure 2: Same as Figure 1 except that only forward projected area is included.

6. Ground Sensitivity Requirement

GBM has a required threshold of < 0.5 photons/cm2-s for ground detection of bursts at 5 sigma significance. There is no definition of this threshold in terms of efficiency as there is for the on-board trigger, nor a prescription for the calculation of the significance. We consider here a significance calculated by combining (root-sum-square) the statistical significance of the burst signal in each detector that is 2 sigma or more above background. As before, we use the 50 keV to 300 keV energy range and a 1 second burst duration. Figure 3 shows the significance level over the sky for a burst of the required threshold flux. The significance is above the required 5 sigma over most, but not all, of the sky. If we apply the same definition of threshold as we do for the on-board trigger – 50% efficiency over the visible sky, then GBM meets this requirement.

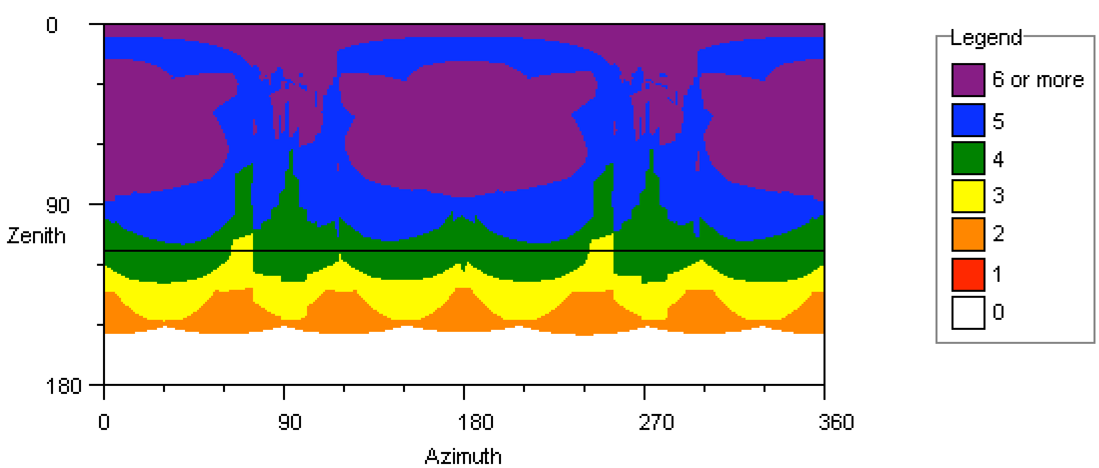

Figure 3: Significance (sigma) of a GRB of 0.5 photons/cm2-s.

7. On-board calibration

GBM will use a similar approach to on-board calibration as was used for BATSE. We will monitor the position of the 511 keV background line and adjust high voltage on the PMTs to keep the line peak at a specific channel number. The smaller size of the GBM detectors means we will have to integrate longer than the 5 minutes used for BATSE, but the better resolution of the GBM detectors offers some compensation. Using a factor of 16 smaller size and an improvement in resolution by a factor of 1.5, we estimate that a 50 minute integration of the background spectra will provide adequate estimates of the line peaks. Therefore, the on-board calibration will not be able to compensate for the small temperature changes within each orbit, but will compensate for longer-term variations. On BATSE, the peak energy was determined very simply by computing a linear background defined at specified channels above and below the peak, and averaging the channel number of events above this background. This will be improved on GBM by using more channels and a quadratic fit to better define the background.

Appendix. Simulation of GBM performance

Many of the numbers presented here were obtained from a computer simulation of the GBM performance. Some details of the assumptions and limitations of that simulation are previded described in this appendix.

The GBM NaI detector response is obtained from preliminary Monte-Carlo calculations carried out by Marc Kippen and includes transmission through the sides and rear of the detectors.

Blockage of the fields of view by the LAT, the LAT radiators, and the spacecraft is accounted for. A sky grid of 1 degree resolution is used. Partial blockage of detectors is accounted for by calculating the visibility of 13 points on the surface of each detector for each sky point. Blockage by spacecraft appendages and other GBM detectors is not included.

The background rates are scaled from BATSE, taking into account altitude effects, pointing directions, and orbital variations. Typical background rates at 565 km are 280 counts/s in the 50 keV to 300 keV band. Where spacecraft scattering and atmospheric scattering are relevant, these are calculated using approximations derived from BATSE data.